SIMULATION-BASED ANALYSIS OF DISTURBANCES IN CONSTRUCTION OPERATIONS

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ABSTRACT

Construction site work is not only influenced by external factors such as weather, soil, available space and traffic conditions, but also by internal ones, in particular the qualifications of the employed personnel and the reliability of subcontractors. These factors are stochastic and thus cannot be predicted, thereby creating great difficulties for construction operations management. The implementation of simulation presents one possibility to support the planning of construction work and thus to secure construction operations. Within a current project, the simulation of construction operations is being supplemented by the registration of construction operations disturbances and their consequences. A database allowing for the recording and classification of disturbances at various construction sites was developed for this purpose. This disturbance database can be integrated into a simulation-based planning tool as an expandable data basis, allowing disturbances to be parameterised and to be taken into account in modelled construction operations. This tool also supports planning operations in Lean Construction such as work flow and resource levelling.

KEY WORDS

Lean construction, simulation of disturbances

DISTURBANCES IN CONSTRUCTION OPERATIONS

Construction site work can only be planned to a certain degree. In addition to external factors such as weather, soil, available space and traffic conditions, a multitude of internal ones such as missing construction documents and material also contribute to disturbances in construction work. Each individual disturbance influences the total construction operations differently. Thus, the demolition of a misplaced concrete wall, caused by a planning error, has a much larger financial and production-logistical impact than the delivery of ready-mixed concrete delayed by several minutes.

Disturbances can be defined as "unexpected occurrences causing an interruption or at least a delay in the execution of tasks; they cause a significant discrepancy between the target and actual data" (cf. REFA 1991a, p. 424). The reason for such a target-actual discrepancy is referred to as a disturbance factor. In construction site work, target data usually refer to time or cost-related operations. Generally, once the construction time and the completion date have been determined, the construction

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methods and resources are planned. Planning is for the most part very rough; daily task plans and controls are very rare. The detailed daily planning is usually carried out by the site foreman, who must react appropriately to relevant disturbances. As a result of lacking feedback, the target data for subsequent construction steps are only available in a very rough form.

Within an ongoing project disturbances occurring during construction site work are registered for the computer-aided simulation of construction operations and processes. In the following, the term construction operations will refer to the total sequence of construction (e.g. the construction of a town house block or a single town house), whereas construction processes represent a sub-section of the complete sequence, such as the pouring of a foundation.

Generally, operational disturbances can be divided into external disturbances, meaning those related to natural, legislative or economical events, and internal disturbances. The latter occur in procurement, sales and construction site work (cf. in the following REFA 1991a, pp. 424).

Disturbances are further subdivided into personnel-, material- and area-related disturbances. Disturbances have to be analysed and classified before they can be dealt with and eliminated. If the cause is known, intervention can then reduce the effects of the disturbance or even remove it.

Further, a closer inspection differentiates between primary and induced disturbance factors. Primary disturbance factors are deviations caused by independent actions within the same area. A primary disturbance arises in construction site work when for example the forms for the pouring of a concrete wall open up because the locks were forgotten during the assembly of the forms. In contrast, an example of an induced disturbance would be the opening of form locks or even the forms themselves because of an error made when calculating the concrete pressure. Induced disturbances are deviations originating in another area.

EVALUATION OF CONSTRUCTION OPERATION DISTURBANCES

Disturbances are primarily evaluated from either a legal or contractual point of view. There are a large number of examinations into this (cf. e.g. Born 1980; Dorn 1997; Heilfort 2003; Hornuff 2003; Husfeld 2006a, 2006b). Moreover many construction companies do a general site analysis with regard to disturbances in general. However, only a few evaluations of disturbances from a detailed point of view have been carried out so far (cf. Lang 1988; Mitschein 1999). This paper focuses on the production site and wants to contribute to the assessment of construction processes by regarding disturbances. It differs from the current analyses, which mostly regard general effects of single disturbances on construction processes. In this contribution the overall assessment of disturbances in production leads to a more realistic view when analyzing construction processes.

There is no data collection available for realistic simulation of construction processes taking into account disturbances. For getting this data a fulltime observation of several construction sites was done. Even minimal disturbances like a crane waiting for 3 minutes or a worker searching for nails were documented.

DISTURBANCE DATABASE

A database based on Microsoft Access was developed for examining construction operations disturbances. The database is divided into four areas:

- Construction Project: general data related to the construction site, such as the project description
- Disturbance Registration: contains data like the actual description of the disturbance, time of occurrence, duration and classification
- Disturbance Elimination: contains information about whether a disturbance can be eliminated immediately or later and about which measures need to be taken (e.g. further work, implementation of an alternative tool etc.)
- Disturbance Effects: contains the temporal and monetary repercussions of disturbances on humans, equipment and materials

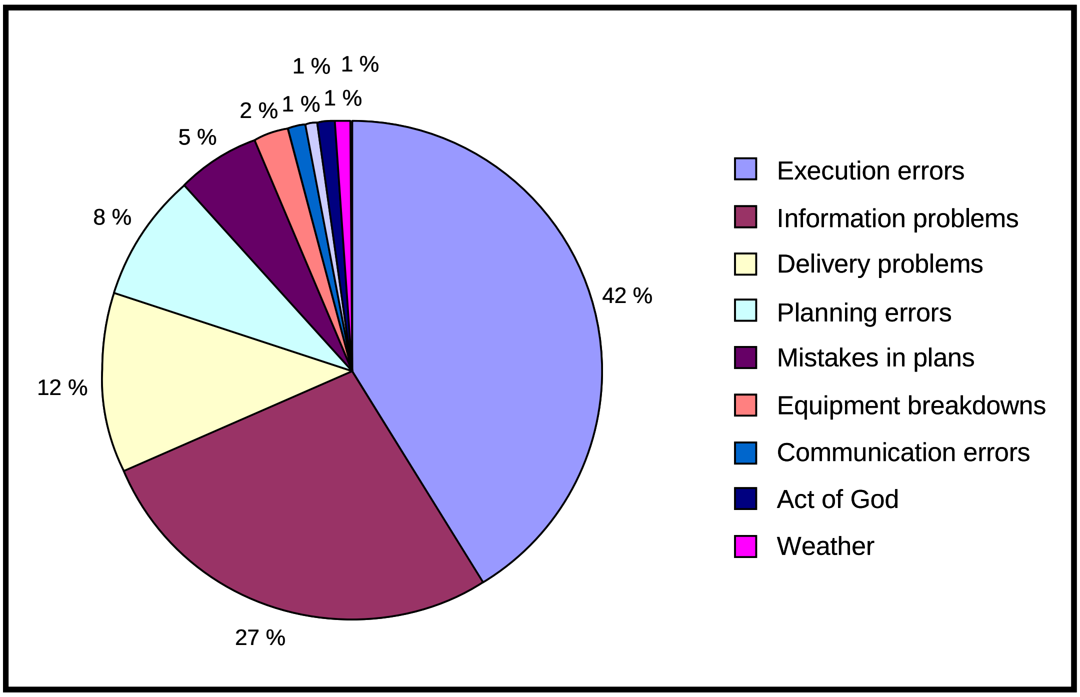

Figure 1: Disturbances registered at construction sites, sorted according to cause

In the following, examples of construction site evaluations will be shown based on the disturbance database. Over a period of 20 days of data collection, a total number of 95 construction operation disturbances were registered. These disturbances are shown in Figure 1, sorted according to their causes.

As shown in Figure 1, execution errors are very frequent. 42 % of all disturbances belong to this category. Information errors and delivery problems follow in the list of disturbance causes with 27 % and 12 %, respectively. In almost 95 % of the recorded disturbances, the personnel were either directly or indirectly affected.

BASIC APPROACHES OF SIMULATION IN CONSTRUCTION

A construction site can be thought of as a production system, differing, however, from manufacturing because general conditions may change at any time. Furthermore, construction represents a highly dynamic production process, which must react to both exogenous and endogenous changes (cf. REFA 1991a, p. 424), and by doing so, planning engineers should try to maintain a continuous work flow (lean construction).

In this context, the experience gained in the manufacturing industry and the related planning instruments come into focus. One approach which has often proven its value in manufacturing enterprises is the simulation of production systems. Using this technique, predictions regarding the expected production situation as well as the effectiveness of resource utilisation can be made.

Should future, not yet existing processes require information about the dynamic behaviour of individual system elements or the entire system (e.g. delays of material deliveries, changes to the material requirements, shortage of personnel capacity) or should testing of a real system not be possible for various reasons (e.g. costs, danger, time), simulation could be a very helpful instrument for the analysis of construction operation disturbances and their effects.

In his article, Franz (2003, pp. 316) gives a review of the current state of simulation applications in construction. He elaborates on both Anglo-Saxon and German research approaches. The application possibilities range from the simulation of complex working sequences such as excavator-truck-operations and concrete-mixer-truck-crane-queues (Franz 1989) or pipe-spool installation (Tommelein 1998) right up to the simulation of earthwork processes (cf. e.g. Gehbauer 1974).

One well-known system for simulating construction processes is CYCLONE (Cyclic Operations Network Technique), which was developed by Halpin (cf. Halpin 1977). The development of CYCLONE can be regarded as an initial point for a range of research within the scope of construction operations simulation and user-friendly modelling. Following this, also other simulation methods like COOPS (Construction Object-Oriented Process Simulation System; Liu, Ioannou 1994), CIPROS (Knowledge-Based Construction Integrated Project and Process Planning Simulation System; Tommelein et al. 1994), STROBOSCOPE (State and Resource Based Simulation of Construction Processes; Martinez 1996) and SIMPHONY (Hajjar, Abourizk 1999) have also been developed. Further approaches refer to simulation-based scheduling methods (cf. e.g. Chehayeb, Abourizk 1998) or describe scheduling methods based on statistical simulation (cf. e.g. Senior, Halpin 1998).

The approaches outlined above are mainly used for a realistic determination of the duration of construction projects. They are frequently limited to single problem areas such as machine-intensive earthworks, high-rise construction (cf. e.g. Esquenazi, Sacks 2006), logistical processes and processes which are similar to those of manufacturing enterprises.

With the present approach an extensive simulation of construction processes is possible.

USE OF THE DATABASE TO SIMULATE CONSTRUCTION OPERATIONS

The disturbance database introduced here can be used to assess the efficiency of construction companies through simulation while taking construction operations disturbances into account. One application would be to represent disturbances (such as e.g. fluctuations in the material delivery and the availability of personnel, machine breakdowns etc.) in a computer model prior to the actual construction phase in order to identify the effects of such disturbances. Counter measures can then be devised to steady the work flow.

Since the occurrence of only one construction operation disturbance during the entire process or during a typical construction operation (e.g. pouring a concrete wall) is very unlikely, more complex disturbance scenarios must be considered. Therefore, the user of a simulation-based planning tool must be given the occasion to create various disturbance scenarios by e.g. changing the type of disturbance or their interarrival time, thus generating variants for disturbed construction operations (cf. Figure 2; time data is in seconds).

This gives construction companies the ability to recognise problems in construction operations at an earlier stage and then to initiate appropriate actions or planning alternatives as early as the work preparation phase. This tool allows the planner to see what the consequences of construction operation disturbances are and enables him to assess and improve complex construction processes during the work preparation phase, before any work has actually been executed. This enables a steady workflow and a levelling of resources.

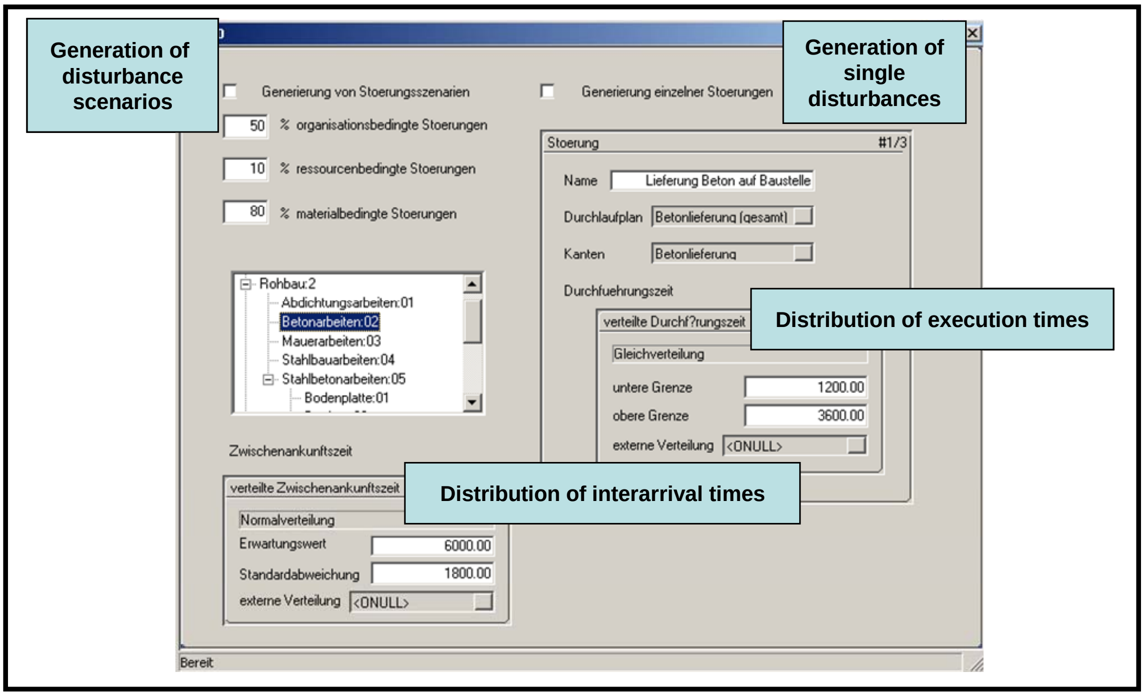

Figure 2: Screenshot of the implementation of the disturbance database

In order to provide the easiest possible handling of such a simulation supported planning tool, it is advantageous to model construction processes in the planning tool as an unique form of network, a so-called throughput diagram (for this cf. e.g. Grobel 1992, pp. 38). The throughput diagrams contain all of the activities necessary for the completion of a construction project, along with their logical sequences. This results in a network diagram showing the predecessor-successor relationships of the individual activities. Figure 3 shows a throughput diagram for the construction of the structural shell of a town house block (in this case a town house block is made up of 4 town houses).

The construction operations to be planned are modelled in a simulation tool. In addition to the temporal-logistical dependencies of the activities to be processed in sequence, in parallel or alternatively, further system elements (such as e.g. personnel) and their attributes (such as e.g. starting date, capacity requirements, working time arrangements) are also entered into the simulation tool (cf. Zülch, Börkircher 2006a).

The simulation of construction operations disturbances can be used as an experimental ground during planning and this allows an early identification of problem areas. Simulation thus helps the planner in estimating temporal and monetary repercussions of planning and process changes as a result of disturbances. Several simulation runs can help to evaluate and demonstrate the possible negative effects of disturbance scenarios observed in traditional construction operations on planned construction operations. This procedure is also known as a sensitivity analysis. This refers to a series of simulation runs of a model, in which at least one parameter, in this case a construction operation disturbance, is changed in each run.

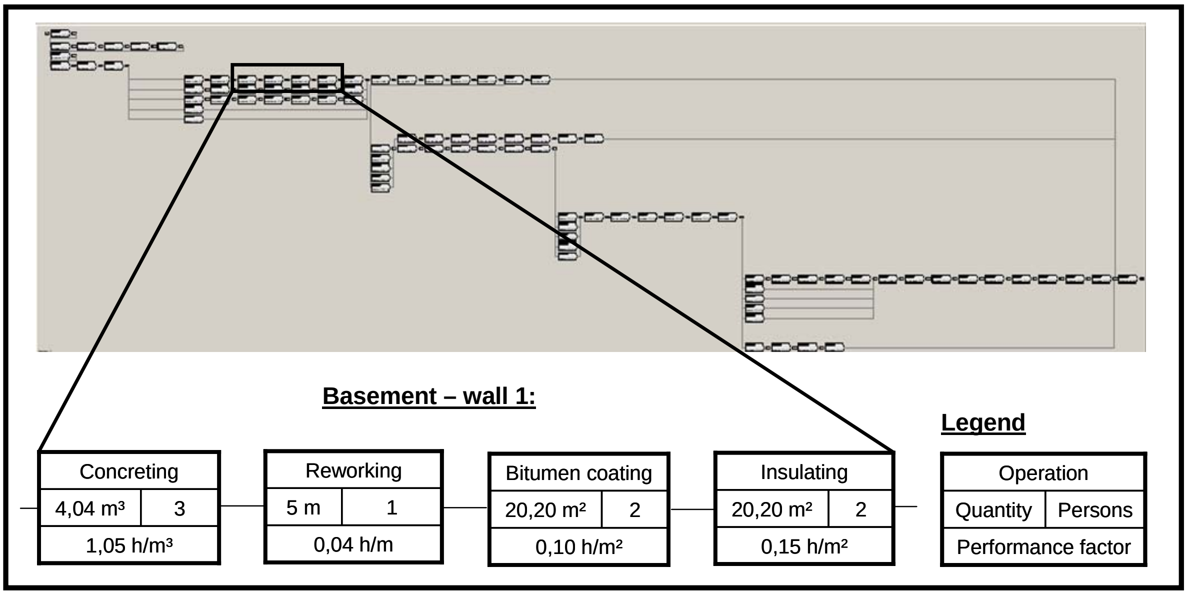

Figure 3: Excerpt from the throughput diagram for the structural shell of a town house block

Figure 4 shows the results of an application for such a scenario simulation. For this purpose, a discrete, event-driven simulation method (in this case *OSim* (Objektsimulator), cf. Jonsson 2000, pp. 181; Zülch, Börkircher 2006b, pp. 564), which was expanded for the simulation of construction work, was used. Using this method, construction operations disturbances from the implemented disturbance database can be applied randomly, here on the process shown in Figure 3. Construction logistical and monetary figures, such as average lead time, average process costs or personnel utilisation, can be calculated after each simulation run. Based on these figures, the influences of (modelled) scenarios on the structural shell construction of a block of town houses, which may occur in reality or which may have already occurred, can be evaluated.

The assessment of the disturbance scenarios fulfils two purposes: For one, the effects of typical construction disturbances on modelled construction operations (or modelled construction processes) can be evaluated regarding construction logistical and monetary criteria. Furthermore, it is also possible to compare various disturbance scenarios with each other. The examples of disturbance scenarios examined here are made up of a variation of personnel-, material- and area-related disturbances as well as their interarrival times (cf. Figures 2). If one were to examine several similar processes influenced by various disturbance scenarios or by sensitivity analysis, conclusions regarding e.g. the robustness of planned processes could be drawn. Disturbance robustness can be thought of as a risk index highlighting a negative deviation from a target state. A comparison of target and actual states using simulation would thus be possible at a very early planning stage. An actual state can thereby not be equated with the actual construction site situation, rather is one of several theoretically possible situations, influenced more or less strongly by construction operations disturbances.

Disturbance scenarios	Average lead time (LTM)	Average process costs (PRC)	Average personnel utilization
Disturbance scenario 1	1771 TU	2487 MU	70 %
Disturbance scenario 2	1641 TU	2887 MU	
Disturbance scenario 3	1615 TU	2631 MU	
Disturbance scenario 4	1736 TU	2965 MU	
Disturbance scenario 5	1702 TU	2643 MU	
Disturbance scenario 6	1676 TU	2825 MU	
Disturbance scenario 7	1598 TU	2754 MU	
Disturbance scenario 8	1797 TU	2900 MU	
Disturbance scenario 9	1710 TU	2797 MU	

LTM deviation – disturbance scenario 8 compared to disturbance scenario 7: 11 %

PRC deviation – disturbance scenario 4 compared to disturbance scenario 1: 16 %

Legend: TU = Time unit; MU = Monetary unit

Figure 4: Simulation results of the disturbance scenarios

SUMMARY AND OUTLOOK

One prerequisite for a successful application of Lean Construction is the possibility to examine construction operations as affected by their influencing variables, and thereby to get a better understanding of construction processes.

Simulation examinations with disturbance scenarios can examine the dynamic system behaviour of construction operations as well as identify critical disturbances. To get realistic data of disturbances of complete construction processes a full time observation is necessary.

A future goal is collecting more detailed data of disturbances in order to increase the quality of the simulation result.

So data collections for various parts of constructions such as road construction or tunnelling are required.

An extensive data collection enables construction companies to improve planning processes and make the planning results more reliable.

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